O'Connor, J.F., 1981.

Growth, Size and Lipid Content Declines of Lake Whitefish (Coregonus clupeaformis) in Lake Winnipeg following Recovery of the Fishery.

MANITOBA
DEPARTMENT OF NATURAL RESOURCES
Fisheries Branch

MS Report No. 81-23, 34pp.

O'Connor, J. F., 1981.

Growth, Size and Lipid Content Declines of Lake Whitefish (*Coregonus clupeaformis*) in Lake Winnipeg following Recovery of the Fishery.

Manitoba Department of Natural Resources
Fisheries MS Report No. 81-23, 34pp.

ABSTRACT

Lipid content and growth characteristics of Lake Winnipeg whitefish populations were reviewed to determine the cause of the decline in quality of fish in the commercial catch in recent years. Significant correlations existed for lipid content against weight and condition factors for whitefish sampled from Berens River and Grand Rapids areas. There has been a significant decrease in growth rates since the fishery reopened in 1971 after the mercury closure and an abrupt decline in length, weight and condition factors in the commercial catch since 1975. Correlated with the decline in size was an expansion of the whitefish population into Grand Rapids, Berens River, North Channel and Channel areas and a 214% increase in yields from 1975 to 1979. This increase in yield was related to strong year classes that developed during the 1968-1970 period when adult stocks were depressed and the 1974-1975 period when low quotas permitted a high escapement of spawners. The deterioration in quality of whitefish was related to intensified intraspecific competition from expanding populations causing density-dependent responses of growth and condition factor declines. No evidence was found that the growth decline in Lake Winnipeg

whitefish was related to introduction of Clearwater Lake stock. The potential scope for growth-compensatory responses indicates that whitefish stocks could withstand an increase in fishing mortality if quotas were raised. It is concluded that increased exploitation should produce an increase growth rate, a larger size fish in the fishery and a better quality product for the smoker trade.

TABLE OF CONTENTS

	Page
ABSTRACT	i
INTRODUCTION	1
METHODS	3
RESULTS	6
Lipid analysis	6
Lipid content-size relationships	6
Clearwater Lake, Lyons Lake and Lake Winnipeg whitefish growth comparisons	11
Lake Winnipeg whitefish growth regimes	14
Commercial sampling	19
DISCUSSION	22
ACKNOWLEDGEMENTS	32
LITERATURE CITED	33

LIST OF TABLES

Table		Page
1	Age-specific mean fork length, mean weight, mean condition factor and percent maturity of whitefish from Berens River area of Lake Winnipeg, 1980	7
2	Age-specific mean fork length, mean weight, mean condition factor and percent maturity of whitefish from the Grand Rapids area of Lake Winnipeg, 1980	7
3	Percent lipid-weight relationships of whitefish from Berens River and Grand Rapids areas of Lake Winnipeg, 1980	8
4	Percent lipid-length relationships of whitefish from Berens River and Grand Rapids areas of Lake Winnipeg, 1980	8
5	Length-weight relationships of whitefish from Berens River and Grand Rapids areas of Lake Winnipeg, 1980	10
6	Percent lipid-condition factor relationships of whitefish from Berens River and Grand Rapids areas of Lake Winnipeg, 1980	10
7	Exponential growth curves of whitefish from Lake Winnipeg (1980), Lyons Lake (1965) and Clearwater Lake (1965)	12
8	Age-specific mean fork lengths of Lake Winnipeg whitefish from experimental gangs 1972-1980	15
9	Age-specific mean weights of Lake Winnipeg whitefish from experimental gangs 1972-1980	15
10	Length-weight relationships between age groups of whitefish from Lake Winnipeg, 1972-1980	16

11 Exponential growth (length-age) curves for Lake Winnipeg whitefish from experimental nets 1972-1980 17

12 Exponential growth (weight-age) curves for Lake Winnipeg whitefish from experimental nets 1972-1980 17

13 Linear regressions of Walford plots fitted by least squares regressions, Lake Winnipeg whitefish lengths 1972-1980 18

14 Von Bertalanffy growth parameters for Lake Winnipeg whitefish for the period 1972-1980 20

15 Mean ages, lengths, weights, condition factors and total yields of whitefish in the commercial fishery, Lake Winnipeg 1971-1980 ... 21

16 Percent age composition of whitefish in the commercial sample Lake Winnipeg 1971-1980 29

LIST OF FIGURES

Figure		Page
1	Lake Winnipeg showing sampling areas mentioned in the text	4
2	Growth of whitefish from Clearwater Lake 1965, Lyons Lake 1965 and Lake Winnipeg 1980	13
3	Relationship between exponential growth rate in terms of weight and yield, as a measure of relative abundance, of Lake Winnipeg whitefish 1972-1980	27

INTRODUCTION

Lake Winnipeg, known internationally as a source of high quality whitefish (*Coregonus clupeaformis*), has been producing fish for export since 1884. There is a high demand for smoked whitefish in export markets and in 1978/1979 almost 80 percent of the 1,775,500 kg of whitefish purchased by the Freshwater Fish Marketing Corporation from Lake Winnipeg fishermen was classed as medium or large smokers (Bruce Popko personal communication). Fatter whitefish produce a better quality product (Roberta York personal communication); therefore, the market for smoked whitefish is dependent on fish with high lipid content.

Yields of whitefish in the fishery have ranged from 3.4 million kg in 1904 to 0.32 million kg in 1936 (Hewson 1960). During the 1952-1969 period there was a declining trend in catch which was directly attributable to excessive effort and over-exploitation of available stock (Davidoff et al. 1973). Unacceptably high mercury levels in other fish species forced a closure of the entire Lake Winnipeg fishery in 1970 and when the whitefish fishery was reopened in 1971 restrictions were set on the number of licenced summer fishermen and quota. This management measure led to a swift recovery of the fish stocks with steady increases in survival rates, harvests and catch/effort through the 1971-1977 period (Davidoff 1978).

Recently, however, the industry has expressed concern over the size of whitefish in the lake, reporting that they are smaller and thinner than in the past. The FFMC has informed fishermen that they are losing their U.S. markets for smoker whitefish and that this problem is related, in part, to the size of whitefish delivered from the lake. In

1980/81 there was a 13¢ per pound difference between medium export smokers and medium export non-smokers F.O.B. Transcona, and a change in classification of Lake Winnipeg whitefish would result in a substantial loss of revenue to the fishermen. There has been some speculation that the declining quality of whitefish in Lake Winnipeg was related to an inferior strain of fish being introduced via the provincial stocking program which has used Clearwater Lake whitefish as a source of eggs for whitefish fry introductions in Lake Winnipeg.

The objectives of this study were to:

1) determine if a correlation existed between lipid content and size of fish in the lake.
2) determine the extent of the decline in size of whitefish.
3) identify the cause or causes of the decline in size.
4) recommend management measures based on the findings.

METHODS

Whitefish samples were collected from 2 stations on Lake Winnipeg during the summer and fall of 1980 (Fig. 1). The Berens River sample, collected on June 25, was taken with a gang of experimental nylon gillnets of 7.62, 8.30, 89, 95, 102, 108 and 140 mm stretched measure. The Grand Rapids samples were taken with single panel gillnets, 140 mm stretched measure on September 16 and 114 stretched measure on October 31. Each panel was 45.72 m long and 1.83 m deep. All nets were overnight sets of 16 - 20 hour duration.

The fork length of each whitefish was measured to the nearest 2 mm. Weights were recorded to the nearest 20 g on a Chatillon spring scale (Chatillon, Mississauga, Ontario). Six to 10 scales were removed from an area above the lateral line below the anterior edge of the dorsal fin on the left side of each fish. Scales were examined at 24 x and 48 x on a microfiche reader (Data View, Model LF1015) for age determination.

A section of white skeletal muscle ahead of the dorsal fin was exised from each of the 219 whitefish sampled, placed in plastic bags and frozen for later determination of lipid content. Lipid analysis was done on a wet weight basis for all samples according to procedures outlined in Chemical Methods No. 4 Total Fat, Fisheries and Oceans Canada, Fish Inspection Branch (unpublished).

Whitefish growth data from Clearwater Lake stock, second generation offspring from Clearwater Lake whitefish transplanted to Lyons Lake (Loch 1974) and Lake Winnipeg whitefish (Lysack 1981) were compared to determine if introductions of Clearwater Lake stock could be depressing growth rates of Lake Winnipeg fish.

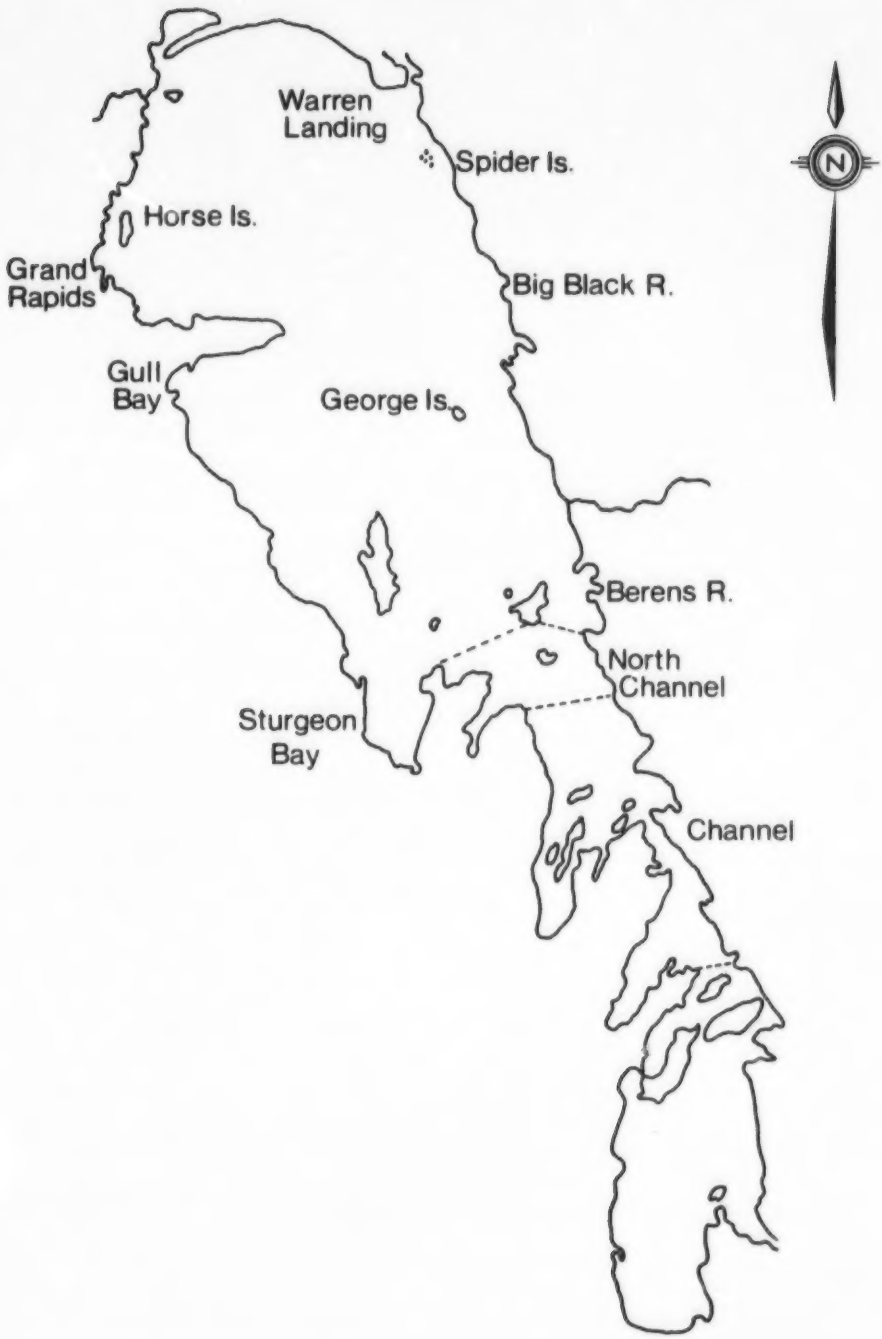

Fig. 1. Lake Winnipeg showing sampling areas mentioned in the text.

Experimental nylon gillnet gangs of 76, 83, 95, 108, 127 and 133 mm stretched measure were fished in the north end of Lake Winnipeg during the summers of 1977-1980. The net panels in each gang were 45.7 m long and 1.8 m deep. Sampling locations and length of sets are described in Lysack (1980). The sampling stations at Sturgeon Bay and Gull Bay were added in 1979.

Commercial catches were sampled during the summer fishery for the period 1971-1980 from three or more of the following stations on the north end of the lake: George Island, Horse Island, Spider Island, Warren Landing, Grand Rapids, Gull Bay, Sturgeon Bay, Big Black River and Berens River. Sampling procedures are described by Davidoff (1978) and Lysack (1980). Dressed weights recorded in the field were converted to round weights using a 12% conversion factor (Doan 1959). Scales were examined at 10 x and 15 x on a triplex microprojector (Bausch and Lomb) for the 1971-1976 period and with the microfiche reader for the period 1977-1980. Scale ages should be precise since there is close agreement between scale and fin ray ages for Lake Winnipeg whitefish (Erickson 1979).

Routine statistical analyses were performed according to Snedecor and Cochran (1967). Growth analysis was done as described by Ricker (1975).

RESULTS

Lipid Analysis

The Berens River whitefish sample was composed of 7 year classes ranging from 3 to 10 years of age with a mean age of 5.57 years. Seventy-five percent of the sample was composed of mature fish (Table 1).

For analytical purposes, the nineteen fish sampled from Grand Rapids area on September 16 were combined with 100 fish sampled on October 31, 1980. This sample had 4 age classes, 3 - 6 years, with a mean age of 4.43. Only 22.7 percent of the sample was mature (Table 2). Mean lengths, weights and condition factors of the Grand Rapids sample were lower than these parameters for the Berens River sample.

Seven of the 100 samples from Berens River analyzed for lipid content were done in duplicate. The mean variation from the actual value was 4.0%. Thirteen of the 119 samples analyzed for lipid content from Grand Rapids were duplicated. These data had an average variation of 8.0% (Marilyn Hendzel, personal communication).

Lipid Content - Size Relationships

Significant correlations were found between percent lipid content of muscle tissue and weight of whitefish in both Berens River and Grand Rapids samples (Table 3). Higher correlations for these parameters existed for the linear regressions developed for the Berens River sample than for the Grand Rapids sample. Semilog and full log transformations did not improve the correlation coefficients of the Berens River regressions but permitted a slight improvement in the coefficients for the Grand Rapids sample.

Table 1. Age-specific mean fork lengths, mean weights, mean condition factors and percent maturity of whitefish from the Berens River area of Lake Winnipeg, 1980.

Age (years)	N	% of Total	Mean length (mm)	Mean weight (gm)	Mean c.f.	Immature	Mature(%)
3	3	3.0	327.00	553.33	1.58	2	1(33.3)
4	11	11.0	330.45	596.36	1.61	9	2(22.2)
5	31	31.0	377.52	885.48	1.63	9	22(71.0)
6	43	43.0	394.81	1072.14	1.74	4	39(90.7)
7	7	7.0	411.43	1204.29	1.71	0	7(100.0)
8	4	4.0	438.50	1320.00	1.58	1	3(75.0)
10	1	1.0	528.00	2700.00	1.83	0	1(100.0)
Total	100					25	75(75.0)
Mean 5.57			384.58	981.82	1.68		

Table 2. Age-specific mean fork lengths, mean weights, mean condition factors, and percent maturity of whitefish from the Grand Rapids area of Lake Winnipeg, 1980.

Age (years)	N	% of Total	Mean length (mm)	Mean weight (gm)	Mean c.f.	Immature	Mature(%)
3	9	7.6	324.89	491.11	1.43	9	3(0.0)
4	64	53.8	354.19	613.59	1.37	59	5(7.8)
5	32	26.9	379.63	827.97	1.51	20	12(37.5)
6	14	11.8	418.14	1062.86	1.44	4	10(71.4)
Total	119					92	27(22.7)
Mean 4.43			366.34	714.83	1.42		

Table 3. Percent lipid - weight relationships of whitefish from Berens River and Grand Rapids area of Lake Winnipeg, 1980.

Lake area	Lipid-weight equation	Correlation coefficient	Test F value, d.f. and significance at P=0.05
Berens River	% lipid = 5.028+0.012 weight	0.681	84.97(1,98) significant
Berens River	% lipid = -61.413+11.389 $\log_e$ weight	0.660	75.52(1,98) significant
Berens River	$\log_e$ % lipid = -2.188+0.721 $\log_e$ weight	0.640	67.88(1,98) significant
Grand Rapids	% lipid = 4.081+0.004 weight	0.305	11.95(1,117)significant
Grand Rapids	% lipid = -8.422+2.377 $\log_e$ weight	0.313	12.64(1,117)significant
Grand Rapids	$\log_e$ % lipid = -1.633+0.534 $\log_e$ weight	0.316	13.00(1,117) significant

Table 4. Percent lipid-length relationships of whitefish from Berens River and Grand Rapids area of Lake Winnipeg, 1980.

Lake area	Lipid-length equation	Correlation coefficient	Test F value, d.f. and significance at P=0.05
Berens River	% lipid = -14.924+0.082 length	0.551	42.88(1,98) significant
Berens River	$\log_e$ % lipid = -8.611+1.909 $\log_e$ length	0.517	35.75(1,98) significant
Grand Rapids	% lipid = 1.312+0.016 length	0.167	3.36(1,117)non-significant
Grand Rapids	$\log_e$ % lipid = 2.916+0.808 $\log_e$ length	0.141	2.38(1,117)non-significant

The correlation coefficient for the linear regression of percent lipid content and length of fish was significant for Berens River but not significant for the Grand Rapids sample (Table 4). Full $\log_e$ transformation did not improve the correlation coefficient for either sample.

Although the length-weight relationships between age groups of whitefish from the Berens River and Grand Rapids samples indicated positive allometric growth, the growth pattern was close to isometrical (Table 5). The isometric condition factor formula then was used in developing correlations between muscle lipid content and condition factor. All correlation coefficients between lipid content and condition factors for both Berens River and Grand Rapids samples were significant (Table 6). Higher correlation coefficients resulted from regressions of lipid content against condition factor than for regressions of either lipid content against weight or lipid content against length for Grand Rapids whitefish. The correlation coefficient of the lipid content - condition factor regression for the Berens River sample was lower than correlation coefficient of lipid content on either length or weight. Full $\log_e$ and $\log_e$ condition factor transformations improved the correlation coefficient for the Berens River sample but they were still lower than the coefficient of regressions of lipid content on either length or weight. Transforming Grand Rapids data improved the correlation coefficient for regressions of lipid content on condition factor. The highest correlation coefficient for lipid content on either length, weight or condition factor

Table 5. Length-weight relationships of whitefish from Berens River and Grand Rapids areas of Lake Winnipeg, 1980.

Lake area	Length-weight equation	Correlation coefficient	Test F value, d.f. and significance at P=0.05
Berens River	$\log_e$ weight = -11.95+3.015 $\log_e$ length	0.920	541.90(1,98)significant
Grand Rapids	$\log_e$ weight = -11.359+3.032 $\log_e$ length	0.907	543.73(1,117)significant

Table 6. Percent lipid-condition factor relationships of whitefish from Berens River and Grand Rapids areas of Lake Winnipeg, 1980.

Lake area	Lipid-condition factor equation	Correlation coefficient	Test F value, d.f. and significance at P=0.05
Berens River	% lipid = 3.575+7.693 c.f.	0.366	15.18(1,98)significant
Berens River	% lipid = 7.002+18.638 $\log_e$ c.f.	0.422	21.26(1,98)significant
Berens River	$\log_e$ % lipid = 2.125+1.213 $\log_e$ c.f.	0.421	21.14(1,98)significant
Grand Rapids	% lipid = 0.330+4.719 c.f.	0.326	13.94(1,117)significant
Grand Rapids	% lipid = 3.855+9.243 $\log_e$ c.f.	0.379	19.63(1,117)significant
Grand Rapids	$\log_e$ % lipid = 1.219+1.944 $\log_e$ c.f.	0.457	30.86(1,117)significant

for the Grand Rapids regressions was achieved for a linear regression of full $\log_e$ transformation of percent lipid content against condition factor.

Clearwater Lake, Lyons Lake and Lake Winnipeg Whitefish Growth Comparisons

Age specific lengths of whitefish sampled with experimental gangs in Lake Winnipeg in 1980 (Table 8) and back-calculated lengths at annuli 1 to 5 for Lyons Lake and Clearwater Lake whitefish (Loch 1971) taken in 1970 are illustrated in Fig. 2. Although $\log_e$ transformed growth data suggested that Lyons Lake fish had a higher slope than Lake Winnipeg fish up to 5 years of age (Table 7), covariance analyses showed no significant difference between slopes ($F = 3.01$, 1 and 4 d.,f. $P = 0.05$) or elevations ($F = 0.014$, 1 and 5 d.f., $P = 0.05$).

Covariance analyses of log transformed growth curves for Clearwater Lake and Lake Winnipeg whitefish up to 5 years of age showed that Lake Winnipeg fish had significantly higher slopes ($F = 19.22$, 1 and 4 d.f., $P = 0.05$) and elevations ($F = 102.81$, 1 and 5 d.f., $P = 0.05$).

There was no significant difference in slopes ($F = 0.46$, 1 and 6 d.f., $P = 0.05$) of the growth curves of whitefish from Lyons and Clearwater lakes but the growth curve of Lyons Lake fish was significantly higher ($F = 53.10$, 1 and 7 d.f., $P = 0.05$) than the growth curve of fish from Clearwater Lake. This means that growth rate between year classes analyzed was not significantly different, but at any given age Lyons Lake fish were significantly larger than Clearwater Lake fish.

Table 7. Exponential growth curves of whitefish from Lake Winnipeg (1980), Lyons Lake (1965) and Clearwater Lake (1965).

Lake	Linear equation	Age range	Correlation coefficient	Test F value, d.f. and significance at P=0.05
Winnipeg	$\log_e$ length = 5.205+0.446 $\log_e$ age	2-5	.999	3062.5(1,3) significant
Lyons	$\log_e$ length = 5.151+0.503 $\log_e$ age	1-5	.993	231.2(1,4)significant
Clearwater	$\log_e$ length = 4.950+0.462 $\log_e$ age	1-5	.983	86.3(1,4) significant

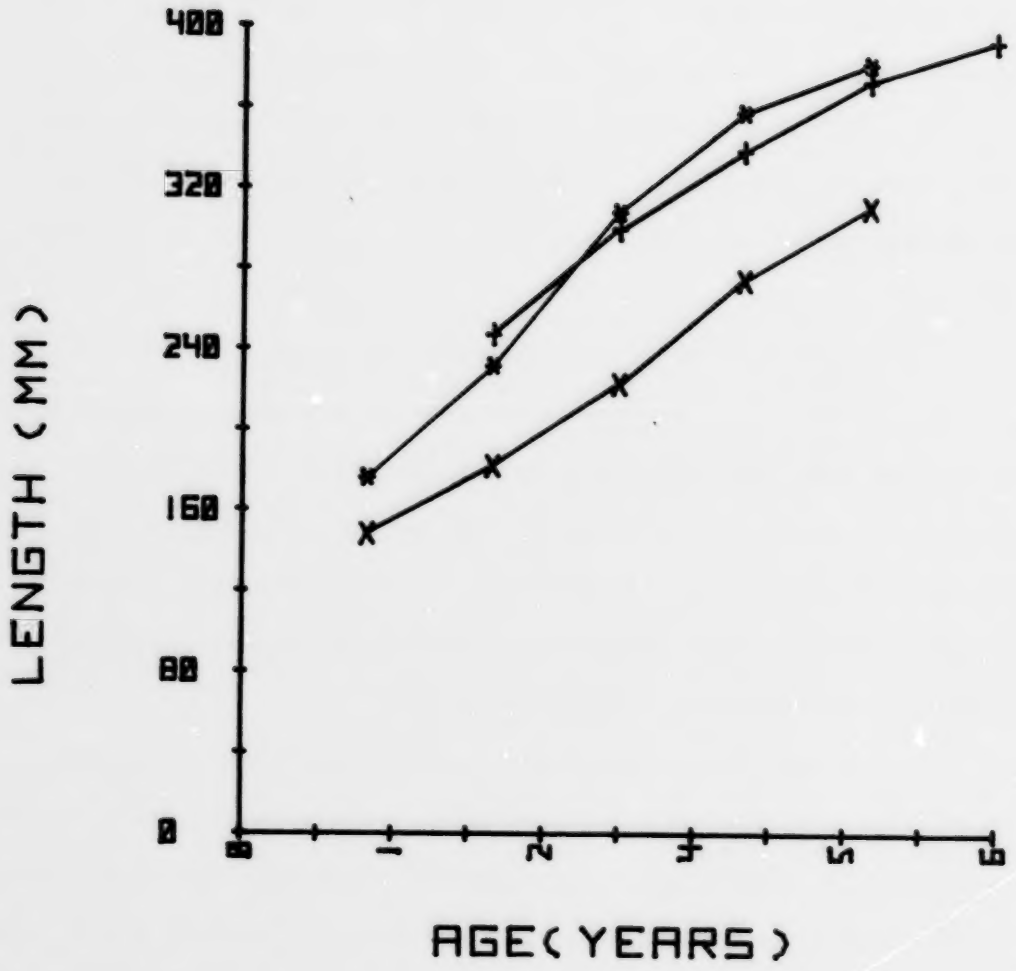

Fig. 2. Growth of whitefish from Clearwater Lake (X) 1965, Lyons Lake (*) 1965, and Lake Winnipeg (+) 1980.

Lake Winnipeg Whitefish Growth Regimes

Age specific mean fork length and mean weight data for whitefish sampled from experimental gangs for the period 1972-1980 are provided in Tables 8 and 9. Covariance analyses of size data for age groups 2 - 7 showed significant difference in slopes ($F = 3.17$, 8 and 36 d.f., $P = 0.05$) and elevations ($F = 7.54$, 8 and 44 d.f., $P = 0.05$) of growth curves of untransformed lengths and in slopes ($F = 19.13$, 8 and 36 d.f., $P = 0.05$) and elevations ($F = 7.49$, 8 and 44 d.f., $P = 0.05$) of growth curves of untransformed weights.

Log transformations of length-weight relationships between age groups showed positive allometric growth for all years although slopes approached isometric conditions in 1975, 1976 and 1978 (Table 10).

Growth rate differences between years were compared by linear regressions of log transformed data of mean lengths and weights at various ages. Slopes of the exponential growth curves showed a general decline in length at age for the period 1972-1980. (Table 11). The decline in slopes of the exponential growth curves was greater for weights (Table 12) than lengths as indicated by the differences in Test F value of untransformed lengths and weights.

The von Bertalanffy growth equation expresses changes in length (L_t) over time as a function of the Brody growth coefficient (K) and asymptotic length (L_∞). The asymptotic lengths of whitefish determined from Walford plots of length at age $t + 1$ against length at age t ranged from 470 mm in 1972 to 590 mm in 1978 (Table 13). The linear relationships of the Walford plots ($r = 0.982 - 0.997$) indicated that the data would fit the von Bertalanffy model, $L_t = L_\infty (1-e^{-K(t-t_o)})$. Linear regressions

Table 8. Age specific mean fork lengths of Lake Winnipeg whitefish from experimental gangs 1972-1980 (N < 5)

Year	(years) 2	3	4	5	6	7	8	9	10	11	12
1972	(254)	310	382	417	443	(508)					
1973	266	327	380	427	451	478	(503)				
1974	264	306	381	427	455	480	(485)				
1975	261	312	370	432	454	468	480	488	(495)		
1976	273	291	344	380	424	449	467	478	491	(519)	
1977	268	289	345	377	410	437	457	474	472	499	(497)
1978	257	302	345	380	409	443	471	482	(524)		
1979	(252)	296	344	375	393	407	429	454	(508)	(516)	
1980	247	299	338	373	392	406	418	440	458	(496)	

Table 9. Age specific mean weights of Lake Winnipeg whitefish from experimental gangs 1972-1980 (N < 5)

Year	(years) 2	3	4	5	6	7	8	9	10	11	12
1972	(227)	400	777	1038	1313	(1885)					
1973	253	479	776	1127	1394	1728	(1885)				
1974	237	382	762	1109	1392	1730	(1970)				
1975	239	421	707	1110	1307	1457	1608	1658			
1976	284	324	549	743	1034	1236	1423	1539	1693	(2060)	
1977	242	303	521	700	911	1088	1266	1399	1409	1932	(1500)
1978	227	371	544	733	942	1189	1440	1589	(2380)		
1979	(260)	361	601	781	898	1010	1216	1485	(2080)	(2147)	
1980	213	366	581	785	927	1034	1125	1336	1555	(1940)	

Table 10. Length-weight relationships between age groups of whitefish from Lake Winnipeg, 1972-1980.

Year	Age Group	Length-weight equation	Correlation Coefficient	Test F value, d.f. and significance at P=0.05
1972	3-6	$\log_e$ weight = -12.920+3.295 $\log_e$ length	0.999	1630.63(1,3)
1973	2-7	$\log_e$ weight = -12.499+3.227 $\log_e$ length	0.999	5091.11(1,5)
1974	2-7	$\log_e$ weight = -12.842+3.282 $\log_e$ length	0.999	4443.40(1,5)
1975	2-9	$\log_e$ weight = -11.687+3.085 $\log_e$ length	1.000	15332.28(1,7)
1976	2-10	$\log_e$ weight = -11.591+3.066 $\log_e$ length	0.999	6651.61(1,8)
1977	2-11	$\log_e$ weight = -12.370+3.190 $\log_e$ length	0.998	1844.87(1,9)
1978	2-9	$\log_e$ weight = -11.651+3.075 $\log_e$ length	1.000	12382.96(1,7)
1979	3-9	$\log_e$ weight = -12.703+3.267 $\log_e$ length	0.999	6796.88(1,6)
1980	2-10	$\log_e$ weight = -12.488+3.235 $\log_e$ length	0.999	5988.95(1,8)

Table 11. Exponential growth (length-age) curves for Lake Winnipeg whitefish from experimental nets 1972-1980.

Year	Linear equation	Age range	Correlation coefficient	Test F value, d.f. and significance at P=0.05
1972	$\log_e$ length = 5.197+0.513 $\log_e$ age	3-6	0.982	54.55(1,3) significant
1973	$\log_e$ length = 5.268+0.474 $\log_e$ age	2-7	0.997	635.92(1,5) significant
1974	$\log_e$ length = 5.216+0.504 $\log_e$ age	2-7	0.992	284.35(1,5) significant
1975	$\log_e$ length = 5.291+0.437 $\log_e$ age	2-9	0.981	154.70(1,7) significant
1976	$\log_e$ length = 5.293+0.403 $\log_e$ age	2-10	0.989	412.39(1,8) significant
1977	$\log_e$ length = 5.402+0.387 $\log_e$ age	2-11	0.991	456.73(1,9) significant
1978	$\log_e$ length = 5.246+0.431 $\log_e$ age	2-9	0.999	3540.32(1,7) significant
1979	$\log_e$ length = 5.316+0.364 $\log_e$ age	3-9	0.991	292.66(1,6) significant
1980	$\log_e$ length = 5.288+0.370 $\log_e$ age	2-10	0.993	492.39(1,8) significant

Table 12. Exponential growth (weight-age) curves for Lake Winnipeg whitefish from experimental nets 1972-1980.

Year	Linear equation	Age range	Correlation coefficient	Test F value, d.f. and significance at P=0.05
1972	$\log_e$ weight = 4.191+1.700 $\log_e$ age	3-6	0.987	78.71(1,3) significant
1973	$\log_e$ weight = 4.478+1.550 $\log_e$ age	2-7	0.999	1742.10(1,5) significant
1974	$\log_e$ weight = 4.269+1.659 $\log_e$ age	2-7	0.994	338.67(1,5) significant
1975	$\log_e$ weight = 4.630+1.352 $\log_e$ age	2-9	0.984	180.12(1,7) significant
1976	$\log_e$ weight = 4.642+1.236 $\log_e$ age	2-10	0.987	269.53(1,8) significant
1977	$\log_e$ weight = 4.538+1.237 $\log_e$ age	2-11	0.991	469.00(1,9) significant
1978	$\log_e$ weight = 4.480+1.326 $\log_e$ age	2-9	0.999	4943.36(1,7) significant
1979	$\log_e$ weight = 4.668+1.189 $\log_e$ age	3-9	0.990	248.01(1,6) significant
1980	$\log_e$ weight = 4.617+1.197 $\log_e$ age	2-10	0.993	508.83(1,8) significant

Table 13. Linear regressions of Walford plots fitted by least squares regressions, Lake Winnipeg whitefish lengths 1972-1980.

Year	Age range	Linear equation	L_∞ (mm)	Correlation coefficient	Test F value, d.f. and significance of P=0.05
1972	3-6	$L_{t+1} = 207.887 + 0.558L_t$	470.33	0.993	78.95 (1,2) significant
1973	3-7	$L_{t+1} = 135.363 + 0.754L_t$	550.26	0.992	133.82 (1,3) significant
1974	3-7	$L_{t+1} = 180.656 + 0.650L_t$	516.16	0.997	399.46 (1,3) significant
1975	3-9	$L_{t+1} = 175.566 + 0.651L_t$	503.05	0.982	108.18 (1,5) significant
1976	3-10	$L_{t+1} = 118.231 + 0.778L_t$	532.57	0.995	575.61 (1,6) significant
1977	3-11	$L_{t+1} = 113.120 + 0.787L_t$	531.08	0.987	233.80 (1,7) significant
1978	3-9	$L_{t+1} = 88.560 + 0.850L_t$	590.40	0.995	409.93 (1,5) significant
1979	3-9	$L_{t+1} = 101.035 + 0.800L_t$	505.17	0.982	106.31 (1,5) significant
1980	3-10	$L_{t+1} = 89.673 + 0.824L_t$	509.51	0.989	237.55 (1,7) significant

of $\log_e (L_\infty - L_t)$ against age t provide the parameters K and t_o (age of fish at length 0) listed in Table 14.

The Brody growth coefficient did not show the same pattern of growth decline for the period 1972-1980 as the slopes of the exponential growth curves.

Commercial Sampling

Mean ages of the commercial sample increased steadily from 4.5 years in 1972 to 6.44 years in 1977 and then declined to 5.54 years in 1980 (Table 15). Mean lengths and weights increased through the period 1971-1975 and then rapidly declined through the 1976-1979 period. The average size of fish caught by fishermen in 1979 was 48 mm shorter and 520 g lighter than the mean size caught in 1975. Average coefficient of condition increased from 1.61 in 1972 to 1.73 in 1974 and decreased thereafter to a low of 1.47 in 1978. Whitefish yields were steady during the period 1973-1976 and then increased dramatically during the 1977-1979 period. Total yield from the lake in 1979 was 985,439 kg (213.9%) more than in 1975. The greatest proportion of this harvest increase was caught in the Grand Rapids, Berens River, North Channel and Channel areas.

Table 14. Von Bertalanffy growth parameters for Lake Winnipeg whitefish for the period 1972-1980.

Year	N	Age Range	Parameters		
			K	L_∞	t_o
1972	2072	3-6	0.585	470.33	1.166
1973	2528	3-7	0.280	550.26	-0.229
1974	1353	3-7	0.432	516.16	0.931
1975	2981	3-9	0.423	503.05	0.650
1976	3242	3-10	0.253	532.57	-0.138
1977	2146	3-11	0.234	531.08	-0.368
1978	4110	3-9	0.169	590.40	-1.172
1979	1412	3-9	0.215	505.17	-1.167
1980	2083	3-10	0.186	509.51	-1.780

Table 15. Mean ages, lengths, weights, condition factors and total yields of whitefish in the commercial fishery, Lake Winnipeg, 1971-1980.

Year	Mean Age	Mean length (mm)	Mean weight (gm)	Mean condition factor	Total yield (kg.rd.wt.)
1971	4.50	399.6	1040	1.63	
1972	5.00	418.3	1180	1.61	227,873
1973	5.17	432.5	1360	1.68	863,610
1974	5.32	438.0	1450	1.73	863,807
1975	5.42	452.2	1500	1.62	864,141
1976	6.12	433.0	1310	1.61	927,027
1977	6.44	425.7	1220	1.58	1,203,600
1978	5.86	413.9	1000	1.41	1,687,750
1979	5.79	404.8	980	1.48	1,849,580
1980	5.54	412.5	1040	1.48	

DISCUSSION

This study indicated that the quality of whitefish, expressed in terms of % lipid content, is highly correlated to the size of the fish, that there has been a significant decline in growth rates and size of whitefish in the catch in recent years, that there is no evidence that this decline is related to introduced stocks and that the decline in size is a normal growth response to increased intraspecific competition from a rapidly expanding whitefish population.

The difference in age composition, maturity and condition factors of the Berens River and Grand Rapids samples can be attributed to seasonal variation in sampling times. Fish sampled in the Berens River area on June 25 were predominantly mature and perhaps close to a peak in seasonal condition. The mean condition factor in the Berens River sample was higher than the means recorded from the commercial sample taken during the 1975-1980 period. The high proportion of non-spawners in the fall sample near Grand Rapids suggested that the mature fish were concentrating elsewhere for spawning.

The low fat content in the younger immature fish and perhaps a seasonal decline in fat content prior to the sampling time contributed to lower correlation coefficients for linear regressions of lipid content against length, weight and condition factors for the Grand Rapids sample than correlation coefficients for those regressions for the Berens River sample. Toneys and Cable (1980) seldom found significant relationships between fat content and length for young-of-the-year green sunfish, *Lepomis cyanellus*, largemouth bass, *Micropterus salmoides*, brook trout, *Salvelinus fontinalis*, and yellow perch, *Perca flavescens*, although there

was a trend toward higher fat content in the larger fish. There also can be a marked variation in seasonal fat content changes within species. Total body fat content in immature and mature yellow perch in Lake Tomaracouta, Quebec, reached their seasonal peak in late June and gradually declined until mid-May the following year at which time there was an abrupt decline during and after spawning. A later seasonal peak and decline was noted in Lake Archambault, Quebec, where fat content in yellow perch peaked in early September (Newsome and Leduc, 1975). Fat content in mature lake whitefish is probably highest in September and early October, just prior to spawning. This means that whitefish fishermen should not be encouraged to fish during winter. Although markets may be available during the winter season, the quality of the whitefish for the export trade is lower.

Condition factors are used to represent the "plumpness" or "well-being" of fish stocks and it was not surprising that there was a higher correlation between lipid content and condition factor than for lipid content against length or weight for the Grand Rapids sample. The lower correlation between lipid content and condition factor than for lipid content against length or weight for the Berens River sample, however, was unexpected.

The significant difference in elevations of growth curves of Clearwater whitefish and second generation offspring from Clearwater Lake stocked in Lyons Lake demonstrates the responsiveness of their growth characteristics to environmental changes. The lack of significant difference in slopes of the two growth curves shows that the greatest

variation in growth occurs in the first year. Although weight data on the two populations were not recorded by Loch (1971), he calculated significant changes in "humpbackness" and concluded that the greater "humpbackness" developed by Lyons Lake fish was also due to environmental influences.

The growth rate of the Clearwater strain in Lyons Lake was at least as fast as the growth of whitefish sampled from Lake Winnipeg. Gillnet selectivity for faster growing fish among younger age groups and growth occurring between winter annulus formation and the sampling date (late June-early July, 1980) create a larger age specific size for Lake Winnipeg fish than would be determined by calculating true growth rates using a regression of fork length on scale radius as was done for Lyons Lake fish. Furthermore, whitefish stocked in Lyons Lake were introduced into less suitable environmental conditions for good growth than those stocked in Lake Winnipeg. Lyons Lake is less productive with a total dissolved solids concentration of 125 ppm (Loch 1971) versus a TDS rearing of 187.2 ppm in northern Lake Winnipeg in 1974 (Kristofferson et al. 1975). Also, hypolimnetic anoxia and high temperatures in the upper 5 m in the epilimnion provided Lyons Lake whitefish with a limited amount of optimal summer habitat. Because of the possibility that the 1980 Lake Winnipeg sample included descendents from the Clearwater Lake strain, these calculations do not prove conclusively that introduced fish can grow as quickly as indigenous fish in Lake Winnipeg. Nevertheless, these comparisons show that whitefish respond very quickly to changing environmental conditions and Clearwater Lake fish introduced into Lake Winnipeg should exhibit growth responses similar to those of native stocks to environmental changes.

Another viewpoint on the effects of introduced stock on Lake Winnipeg whitefish populations was expressed by Kristofferson (1978) who compared genetically based characteristics, gill raker number and glycerol - 3 - phosphate dehydrogenase b allele frequencies, of whitefish from Clearwater Lake with those from Lake St. Martin-Dauphin River and from Grand Rapids. There are significant genetic differences between Clearwater, Lake St. Martin-Dauphin River and Grand Rapids whitefish and Kristofferson concluded that hatchery plantings at Grand Rapids and Dauphin River were not contributing to local spawning stocks.

The question of whether or not hatchery plantings are augmenting the Lake Winnipeg fishery, however, has still not been resolved. Since samples from Lake St. Martin-Dauphin River and Grand Rapids were taken from spawning concentrations, conclusions on the effects of hatchery introductions on the fishery can only be made if introduced whitefish return to their release site to spawn. These fry, the progeny of lake spawners, are incubated in artificial conditions in hatcheries and released over offshore reefs and it is questionable whether they would be imprinted with any olfactory, thermal, rheotropic or visual clues needed to orient them to their release site. Imprinting is a process restricted to a brief period usually at an early stage of development; nothing is known of the times of sensitive imprinting periods, or the duration of the imprinting process (Harden-Jones 1968). Salmon fry may undergo a series of imprinting processes corresponding to each major change in environment (Harden-Jones 1968) and whitefish fry may undergo similar imprinting processes, e.g. spawning ground, Lake St. Martin, Dauphin River, Lake Winnipeg, and it may be important that returning spawners follow exactly the reverse sequence. It is quite possible

that introduced whitefish, denied any imprinting clues during their early life history phases, disperse freely throughout whitefish zones in the lake during spawning.

There may have been some minor limnological and biological changes in Lake Winnipeg during the 1970's due to a slight increases in TDS, bicarbonate content and benthic production (Kristofferson et al. 1975), but there is little evidence that other environmental parameters that could play a role in whitefish growth rates such as temperature (Healey 1975), predator abundance, or interspecific competition for available food supply (Bidgood 1973) changed enough to cause the rapid decline in growth rates between 1974 and 1976 (Fig. 3).

The decline in slope of the exponential growth curve during the mid-seventies was not paralleled by the Brody growth coefficient in the von Bertalanffy growth equation. The Brody growth coefficient, though, is very sensitive to changes in asymptotic size of the population sample. For example, the addition of 1 year class from 1972 to 1973 to include age 7 in the growth curve resulted in an increase in ultimate size from an unrealistically small 470.3 mm in 1972 to 550.3 in 1973 and a decrease in Brody growth coefficient from 0.585 to 0.280 changing the estimated growth rate from the [redacted]est to among the [redacted]est of the 9 years of data analyzed. The passage of older year classes through the fishery in 1977 and 1978 also produced an increase in asymptotic size and growth rates predicted by the von Bertalanffy growth equation.

The number of older year classes in the experimental sample increased steadily through the 1972-1977 period and corresponded to regular increases in mean age of the commercial catch. The continuing increase in mean age for 2 years after the initial decline in size in the commercial catch in 1976 can be attributed to the recruitment of slower growing older

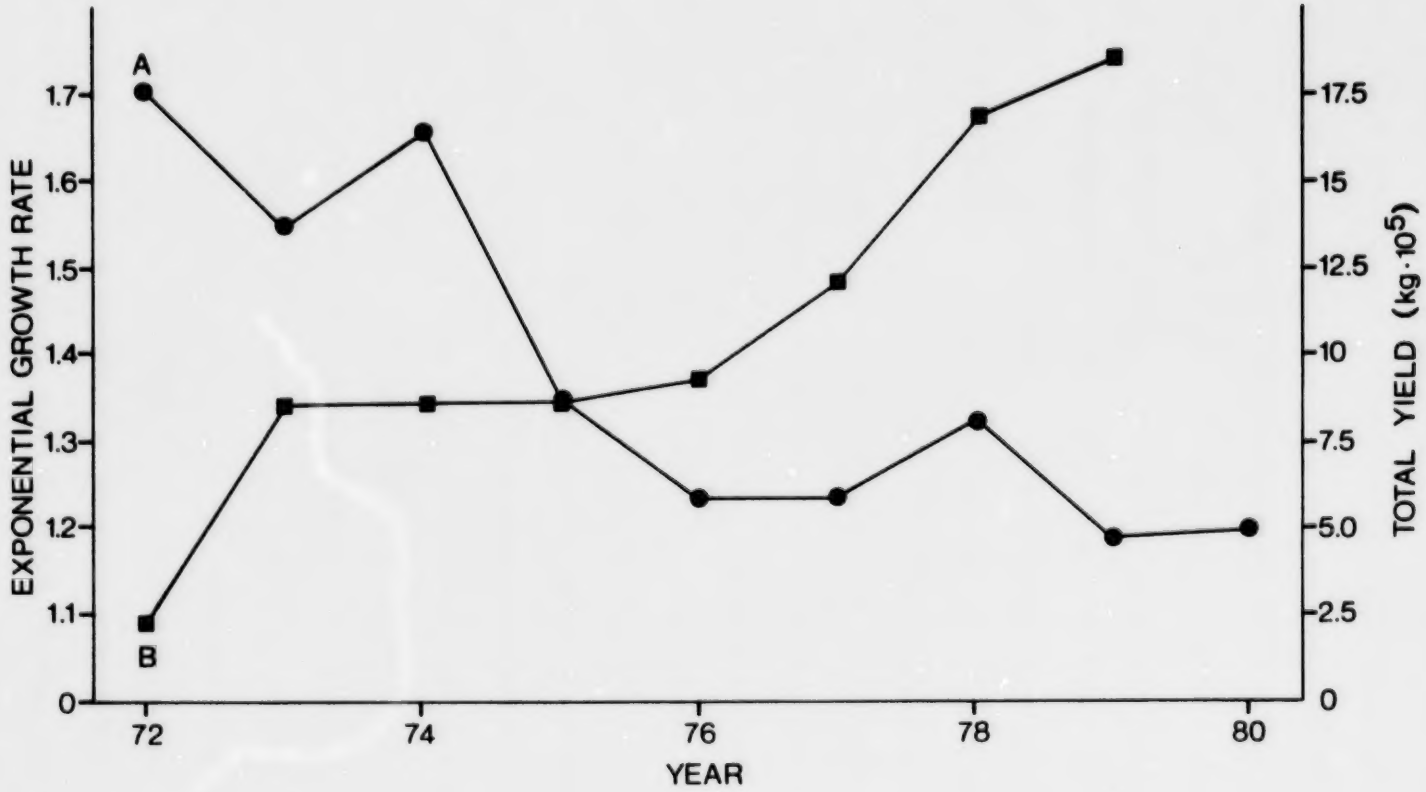

Fig. 3. Relationship between exponential growth rate in terms of weight (curve A) and total yield, as a measure of relative abundance (curve B) of Lake Winnipeg whitefish, 1972 - 1980.

individuals into the fishery and a change in growth rate which underwent a significant decline in length elevation ($F = 8.607$, 1 and 9 d.f., $P = 0.05$) and weight slope ($F = 22.603$, 1 and 8 d.f., $P = 0.05$) and elevation ($F = 11.418$, 1 and 9 d.f., $P = 0.05$) between 1974 and 1976 for ages 2 - 7.

The mean weight of whitefish in the commercial fishery in 1974, 1450g, and 1975, 1510g, were the highest recorded for the 1944-1980 period (Davidoff et al. 1973; Davidoff 1978). Although the mean sizes of fish in 1979 and 1980 were similar to those recorded during the late 1960s when the whitefish fishery was near collapse, the decline in mean weight this time was more alarming to the industry because it was so pronounced.

The decline in mean size of fish in the commercial catch subsequent to 1975 was due to the passage of strong 1968-1970 cohorts through the fishery (Table 16) and growth rate changes during the period 1974-1976. The development of strong 1968-1970 cohorts coincided with declines in abundance of adult stock. This population response is consistent with Healey's (1975) observation in unexploited Northwest Territories lakes that recruitment of young whitefish is regulated by the established population of adult fish. If this control mechanism is operating in Lake Winnipeg it would bring into question the benefit of stocking fry when adult stocks are strong. Environmental factors also appear to be controlling spawning success and year class strength of river and lake tributary spawners. There were highly significant correlations for both September-November monthly discharges and November-March monthly discharges in the Dauphin River for the 1960-1974 period and winter whitefish harvests in Lake St. Martin 5 years later (O'Connor 1980). The modal age in the fishery was 5 years.

Table 16. Percent age composition of whitefish in the commercial sample Lake Winnipeg, 1971-1980.

Age Class	Year									
	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
2									0.04	
3	.15								0.16	.07
4	50.47	13.73	11.62	11.10	11.59	9.50	2.55	2.66	4.95	8.24
5	48.13	72.66	61.30	79.10	46.84	23.78	29.87	46.17	39.28	40.58
6	1.20	13.14	24.84	35.28	31.63	30.62	25.64	30.49	38.39	34.44
7	0.05	0.41	2.04	4.40	7.27	22.11	20.18	8.84	12.60	12.56
8		0.06	0.15		2.37	9.35	11.67	6.02	2.66	3.17
9					0.19	3.04	5.35	3.69	0.52	0.81
10						1.22	3.47	1.19	0.56	0.14
11						0.08	0.97	0.54	0.32	
12									0.20	
13									0.08	
14									0.04	
15									0.04	

The decline in growth in 1975 and 1976 was closely followed by a rapid expansion of whitefish into walleye and sauger zones: Berens River and Grand Rapids in 1977, North Channel in 1978, and Channel in 1979 The increased abundance of stocks in 1978 and 1979 could be attributed to the large size of fish and small quotas in 1974 and 1975. The large size reduces the number harvested to fill the quota and permits a large escapement of spawners. Progeny from these year classes may have been forced out of the north end whitefish zone by intraspecific competition for food and space and these year classes are now supporting whitefish fisheries in the Channel area and "pickerel pockets". The effects of the increase in intraspecific competition were also apparent in the condition factors which declined abruptly as the population expanded during 1978 and 1979.

The quota increases in the summer whitefish fishery in the north end (1971 - 390,089 kg, 1972 - 399,161 kg, 1976 - 524,897 kg, 1977 - 602,733 kg, 1978 - 698,720 kg) were not sufficient to prevent a significant decline in growth rate, condition factors and mean size of fish in the fishery. However, there has been a steady decline in mean age and relative abundance of older age groups since 1977. In 1977, 22.0% of the commercial catch was composed of 8 year and older fish; these age groups represented 4.1% of the 1980 harvest (Table 16). Furthermore, Lysack (1980, 1981) calculated survival rates of 0.26 - 0.31 and a mean age of maturity close to the mean age of the catch. These parameters indicate that the fishery is undergoing moderate exploitation. The current management strategy of annual quota increases should continue in order to trigger growth compensation responses (Ricker 1958; Healy 1975) but the stocks and fishery will have to be monitored closely to maintain a stable fishery through quota adjustments.

This report reveals that quotas could have been expanded more rapidly in the mid-seventies, but the cautious management program that was followed produced a whitefish fishery in walleye and sauger zones that fortuitously filled quotas and provided a measure of conservation for these species that otherwise would have been under severe pressure from recent quota increases.

Although increased whitefish quotas should lead to an increased growth response in stocks, a larger size fish in the fishery and a better quality product for the smoker trade, they may also lead to a decline in whitefish yields that are now over 500,000 kg more than the average historic yield from the lake.

ACKNOWLEDGMENTS

I would like to extend a special thank you to M. Hendzel, Regional Chemist, Fisheries and Oceans for doing the lipid analysis. Appreciation is expressed to K. Campbell, K. Kristofferson, B. Govereau, A. Desrosiers and J. Beyette for collecting and submitting the samples. Thanks are extended to A. J. Derksen and W. Lysack for editing the manuscript and W. Lysack for drafting the figures. Scales were read by H. Metheringham. N. Markus and C. Caverly did an excellent job typing the report.

LITERATURE CITED

Bidgood, B. F. 1973. Divergent growth in two lake whitefish (*Coregonus clupeaformis*) populations. J. Fish. Res. Board Can. 30: 1683-1696.

Davidoff, E. B. 1978. Changes in the population of lake whitefish (*Coregonus clupeaformis*) in Lake Winnipeg from 1971-1977. Man. Dept. of Mines, Nat. Res. and Environ. MS Rep. 78-80, 35p.

Davidoff, E. B., R. W. Rybicki, and K. H. Doan. 1973. Changes in the population of lake whitefish (*Coregonus clupeaformis*) in Lake Winnipeg from 1944 to 1969. J. Fish. Res. Board Can. 30: 1667-1682.

Doan, K. H. 1959. The 1959 summer whitefish fishery on Lake Winnipeg. Man. Dept. Mines Nat. Res. MS Rep. 14p.

Erickson, C. M. 1979. Age differences among three hard tissue structures observed in fish populations experiencing various levels of exploitation. Dept. of Natural Resources, MS Rept. 79-77, 31p.

Healy, M. C. 1975. Dynamics of exploited whitefish populations and their management with special reference to the Northwest Territories. J. Fish. Res. Board Can. 32: 427-448.

Harden-Jones, F. R. H. 1968. Fish Migration. St. Martin's Press, Inc. New York, NY. 325p.

Hewson, L. C. 1960. A history of the Lake Winnipeg fishery for whitefish, (*Coregonus clupeaformis*) with some reference to its economics. J. Fish. Res. Board Can. 17: 625-639.

Kristofferson, K. H. 1978. Evidence for the existence of subpopulations of Lake Whitefish, *Coregonus clupeaformis* (Mitchell) in Lake Winnipeg. M.Sc Thesis. Univ. Manitoba, Winnipeg, Man. 94p.

Kristofferson, K. H., D. R. Toews and A. J. Derksen. 1975. Limnological study of the north basin of Lake Winnipeg, 1974. Man. Dept. Mines, Res. and Environ. Mgmt. MS Rep. 75-5, 54p.

Loch, J. S. 1971. Phenotypic variation in the Lake Whitefish as induced by introduction into a new environment. M.Sc Thesis. Univ. Manitoba, Winnipeg, Man. 96p.

Lysack. W. 1980. 1979 Lake Winnipeg fish stock assessment program. Man. Dept. Nat. Res. MS Rep. 83-30, 118p.

1981. 1980 Lake Winnipeg fish stock assessment program. Man. Dept. Nat. Res. MS Rep. 81-20, 67p.

Newsome, G. E., and G. Leduc. 1975. Seasonal changes in fat content in the yellow perch (*Perca flavescens*) of two laurentian lakes. J. Fish. Res. Board Can. 32: 2214-2221.

O'Connor, J. F. 1980. Lake St. Martin whitefish production, memo, 6p.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Bull. Fish. Res. Board Can. 119: 300p.

1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191: 382p.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical Methods. 6th ed. Iowa State Univ. Press, Ames, Iowa, 593p.